VII.5 Advanced Net-Shape Insulation for Solid Oxide Fuel Cells

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Objectives

- Demonstrate the feasibility of using a proprietary material – CERCANAM® (Ceramatec Castable Nano Material) – as a functional insulation material in high-temperature solid oxide fuel cell (SOFC) operational environments.
- Fabricate 6” × 6” × 1/4-1/2” CERCANAM plates with minimal post-machining.
- Demonstrate appropriate thermal shock resistance and thermal cycling resistance for 6” × 6” × 1/4-1/2” CERCANAM plates at temperatures up to 1000°C.
- Demonstrate the intermediate-term (100 h) thermochemical stability of CERCANAM materials in high-temperature air and fuel environments.
- Demonstrate the short-term (100 h) stability of SOFC electrodes and electrode/electrolyte interfaces in fuel/air passed over CERCANAM at 850°C.
- Demonstrate adequately low thermal conductivity and tolerable cost for application as SOFC insulation.

Approach

- Fabricate 6” × 6” × 1/4-1/2” CERCANAM plates using modified processing routes amenable to low-cost bulk fabrication of custom shapes.
- Perform thermogravimetric analysis (TGA) of CERCANAM specimens in air, hydrogen and carbon dioxide, as well as weight change measurements after exposure to syngas.
- Perform testing of solid oxide fuel cells with CERCANAM in the air and fuel streams and monitor fuel cell performance during the test.
- Measure thermal conductivity using conventional laser flash diffusivity analysis (LFA) as well as a guarded hot-plate apparatus.
- Perform a preliminary cost analysis to estimate production costs of CERCANAM in large-scale production.

Accomplishments

- 6” × 6” CERCANAM parts were fabricated with minimal warpage.
- These parts showed excellent resistance to aggressive thermal cycling and thermal shock exposures.
- Lightweight (0.9 g/cc), low thermal conductivity (0.3-0.4 W/m/K), high purity (<0.1% SiO_2) compositions were developed. CERCANAM specimens exposed to flowing air and fuel on the cathode and anode side, respectively, of both yttria-stabilized zirconia (YSZ) and lanthanum strontium magnesium gallate (LSGM; $La_{1-x}Sr_xGa_{1-y}Mg_yO_3$; lanthanum gallate doped with Sr on the A-site and Mg on the B-site) based SOFC button cells resulted in no degradation in SOFC performance in intermediate-term (100-200 hour) tests.

- CERCANAM specimens showed excellent resistance to significant temperature gradients; excellent resistance to coking in reformed natural gas (and no change in thermal conductivity); and excellent chemical stability in hydrogen, CO_2 and syngas.
- Raw-materials cost for CERCANAM production were shown to be below $125/ft^3, and since the production processes are similar to conventional ceramics, it is clear that production cost targets will easily be below the insulation cost target set by the Solid State Energy Conversion Alliance (SECA) of $345/ft^3.

Future Directions

- Establish detailed processing-microstructure-property-cost correlations for CERCANAM and optimize materials processing to achieve the lowest possible thermal conductivity and cost in CERCANAM materials.
- Demonstrate long-term stability (>2000 hours) of YSZ and LSGM button cells with selected CERCANAM compositions in the fuel and air sides.
- Demonstrate application of CERCANAM to insulate a simulated full-scale SOFC stack.
- Fabricate and evaluate tubular high alumina sintered porous/dense layered structure for net-shape insulation in tubular SOFCs.
- Perform detailed manufacturing cost analysis for CERCANAM and the porous/dense laminated structures to provide data that can be utilized in global SOFC cost models by SECA teams.
- Identify specific insulation requirements for SOFC designs of various SECA vertical teams and identify appropriate CERCANAM compositions with the optimal combination of thermal conductivity, strength, and cost.

Introduction

As solid oxide fuel cell (SOFC) technology matures, cost considerations are becoming the primary barriers to commercialization. The cost threshold for commercialization of SOFCs is believed to be $400/kW, a target set by SECA, a consortium of government, industrial partners and national laboratories/universities focused on development of cost-effective fuel cell-based power generators. As the cost of other components of the system (electrodes, electrolytes, and interconnects) become lower due to increased production and improved yield through technology maturation, the cost of insulation as a percentage of the total cost is becoming higher. SECA has identified a cost target for SOFC insulation of about $16-20/kW (based on $400/kW for the overall system), which translates to $300-350/ft^3 of insulation material. For comparison, the cost of high-purity microporous insulation is around $1200/ft^3, and the current status of insulation cost for the stack is about $30-40/kW.

There are major technological issues associated with use of the currently available low-cost insulation materials. Most current materials are processed from aluminosilcate fibers, aluminosilcate-based reaction bonded ceramics or low-grade alumina, all of which have significant silica content. It is now well known that materials with substantial silica contents are poor choices for SOFC systems where spent fuel recirculation is used as an option for increasing fuel efficiency, such as in the tubular design employed by Siemens-Westinghouse Power Corporation. Testing of SOFC performance, when operated with partially reformed natural gas blown through a porous silica-rich insulation, has shown that SOFC performance starts to decline after 1000 h of testing. Some types of high-purity alumina (low silica) insulation are commercially available and have been shown to have good performance in SOFC environments. However, the sintered, porous insulation materials generally have relatively high thermal conductivity (>0.6 W/mK) and density to make them practical for SOFC applications on a weight/kW basis. In addition, sintered materials generally need substantial post-machining to form the desired shapes, which increases processing costs. Fiberous insulation materials, on the other hand, can be cut and shaped easily, but the high-purity fiber-based materials are

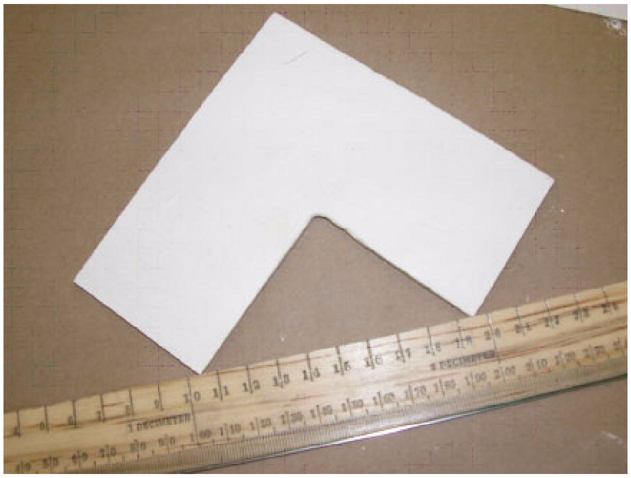

Figure 1. An L-shaped CERCANAM Specimen That Showed No Significant Damage after 9 Thermal Cycles from Room Temperature to 850°C, Followed by an Aggressive Thermal Shock Test

cost-ineffective for SOFC applications. Therefore, there is a current and pending need for low-cost, high-performance insulation for SOFC systems.

Approach

Over the past three years, Ceramatec has been developing castable alumina-based nano- and sub-micron ceramics for micro-components that require very high dimensional tolerances. The new family of materials, called CERCANAM, is based on the idea that precision components can be fabricated through reaction bonding. In 2003, Ceramatec was awarded a Phase I Small Business Innovation Research (SBIR) Grant by the Department of Energy (DOE) to develop SOFC insulation. The goal of Phase I was to demonstrate that the process and material were suitable for fabricating larger parts with sufficient thermomechanical and thermochemical stability in SOFC operating environments and could meet SOFC commercialization cost targets. Based on the substantial progress achieved in Phase I, Ceramatec was recently notified of a Phase II grant to continue development of CERCANAM SOFC insulation to near commercial scale.

Results

The Phase I project was highly successful in meeting all of the technical targets. CERCANAM

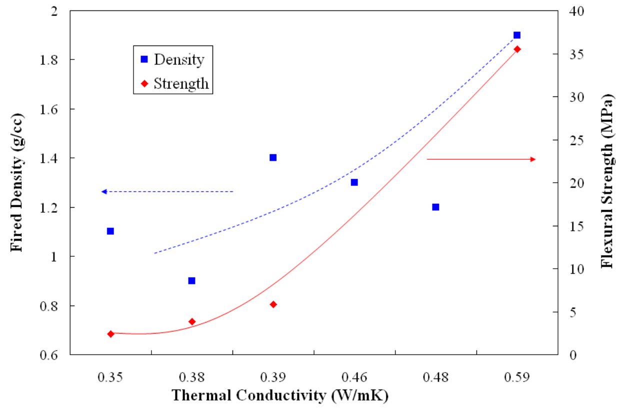

Figure 2. Plot Showing a Trade-off Between Thermal Conductivity and Strength of CERCANAM Materials

parts with dimensions 6” × 6” could be fabricated with minimal warpage, and parts of these dimensions showed excellent resistance to aggressive thermal cycling and thermal shock exposures from typical SOFC operating conditions to ambient temperature. Figure 1 shows an L-shaped CERCANAM slab subjected to thermal cycling and thermal shock. No degradation was seen after 9 cycles to 850°C followed by in-furnace air cooling. After the thermal cycling tests, the same part was subjected to an aggressive thermal shock test which involved rapid air cooling from 850°C to room temperature at ~3600°C/hr. The part survived this test also with no significant damage. CERCANAM specimens also showed excellent resistance to significant temperature gradients, excellent resistance to coking in reformed natural gas (with no change in thermal conductivity), and excellent chemical stability in hydrogen, CO_2 and syngas.

CERCANAM compositions with bulk density lower than 0.9 g/cc and thermal conductivities as low as 0.3-0.4 W/m/K (which meet SECA targets) were developed. As expected, a trade-off between thermal conductivity and flexural strength was observed – both flexural strength and thermal conductivity decrease with decreasing density as shown in Figure 2. CERCANAM specimens exposed to flowing air and fuel on the cathode and anode side, respectively, of SOFC button cells (both YSZ- and LSGM-based) resulted in no degradation in SOFC performance in intermediate-term (100-200 hour) tests. An example is provided in Figure 3 which indicates that there is

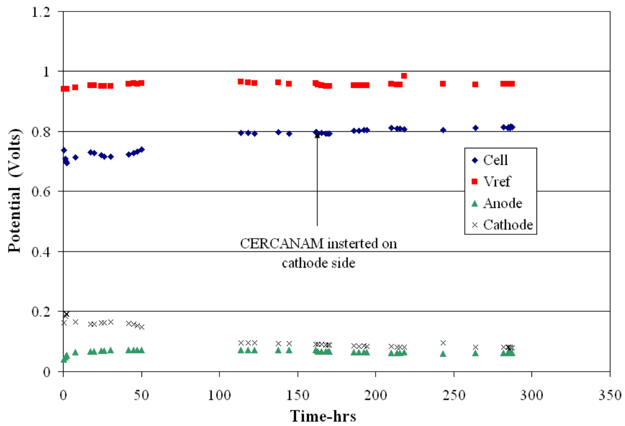

Figure 3. An Example of Cell Test Data Showing No Effect of Introducing CERCANAM on the Cathode Side of a YSZ-based SOFC Button Cell

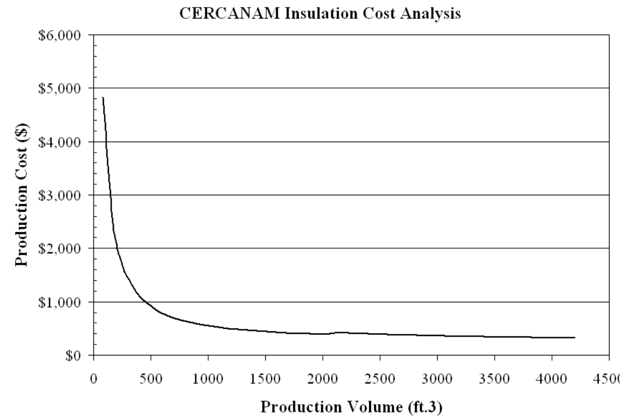

Figure 4. Preliminary Production Cost Analysis for CERCANAM Insulation Materials Which Indicates That the Cost Approaches the SECA Target of $345/ft^3 at a Production Volume over 3,800 ft^3/year

no degradation in fuel cell performance when CERCANAM is introduced on the cathode side of YSZ-based SOFC button cells. Similar tests have also shown no effect when CERCANAM is introduced on the anode or cathode side of YSZ- or LSGM-based button cells.

In addition, raw-materials cost for CERCANAM production was shown to be about $125/ft^3 (assuming a density of 0.9 g/cc). Since the production processes are similar to conventional ceramics, it is clear that production cost targets will easily be below the SECA targets. Figure 4 shows the results of a preliminary production cost analysis carried out in the Phase I project utilizing some simplifying assumptions. The analysis shows that the cost starts to approach the DOE cost target at an annual production volume of over 3,800 ft^3/year.

Conclusions

To ensure commercially viable SOFC systems, it is critical to develop low-cost, high-performance insulation materials. CERCANAM materials were shown to have sufficiently low thermal conductivity, sufficiently low cost, sufficiently high thermal/chemical stability and sufficiently high thermal cycling/thermal shock resistance for application as SOFC insulation. Clearly, CERCANAM is a promising option for SOFC insulation from both technical and commercialization perspectives. Future work in the Phase II project will be directed at developing low-cost, high-yield manufacturing routes and demonstrating long-term operation of SOFC button cells and simulated stacks with CERCANAM insulation.

Patents

No patent applications have been submitted yet. It is anticipated that a provisional patent will be filed in the first year of the Phase II project.